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# Effect of additive materials to concrete on γ-ray absorption coefficient

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**Abstract** : Gamma-ray absorption coefficient in some shielding materials, such as, iron, brass, lead and concrete, is measured experimentally in the present study using a Cs-137 source of energy 0.662 MeV.

Two types of concrete samples are used , ordinary concrete and concrete with additive fractional weights of iron or brass or lead materials. Experimental measurements are carried out for single-layer absorbers. The dependence of gamma-ray absorption coefficient on the atomic number, and density of the absorber material is taken into account. The results showed that for concrete, the value of gamma-ray absorption coefficient can be increased if a material of high atomic number ( or density ) is added to it .

**Keywords** : Radiation protection, shielding material, γ-ray absorption coefficient

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The mechanism of absorption of gamma-ray by matter is different from that of charged particles, as indicated by the higher penetration power of gamma-ray[1,2]. When a beam of gamma-ray of intensity *I* is incident on a slab of small thickness , the change in the transmitted beam through the slab is proportional to and *I*, and is given by [1]

(1)

where the proportionality constant is called the absorption coefficient. If all the photons of gamma-ray have the same energy, is independent of *x*, and the above relation becomes

(2)

which gives the intensity *I* of the transmitted beam for an initial intensity $I_o$ and absorber thickness *x* of the given material. When the fractional transmission on logarithmic scale is plotted against the absorber thickness on a linear scale, the result is a straight line with the slope of the line giving .

The main purpose of the shields is to protect operating personnel from possible injury by nuclear radiation, and in some cases, to reduce radiation exposure. The shield used for the first case is called biological shielding, and is called thermal shield for the second case.

Since the radiation entering the shield from the reactor can produce internal heating and possibly causes radiation damage to shield materials, it is necessary to estimate the types and intensities of radiation through the shields [3,4] . The shielding materials are divided according to their functions. The heavy or moderately heavy elements, which are used to attenuate the gamma radiation and to slow down very fast neutrons to 1 MeV; the hydrogenious materials, which are used to moderate neutrons having energies below 1 MeV; and finally some materials, notably those containing boron, which capture neutrons without producing high energy gamma-ray .

Many authors [ 5-18] have studied gamma-ray absorption coefficient, the attenuation of neutron from a point source, the design method of compensational shield, and reactor shielding materials.

The present study aims to investigate the gamma-ray absorption coefficient in some shielding materials , and to increase its value for ordinary concrete by adding materials of high atomic numbers in order to reduce the shielding cost.

The measurement system consists of several electronic devices such as : ( 7.62 cm × 7.62 cm ) NaI ( Tl) detector (BIKRON), photomultiplier and preamplifier ( ORTEC 276) , amplifier (ORTEC485), bias supply (ORTEC 478) and multichannel analyzer (Norland 5300). The radioactive source used is

Cs- 137 ( Amersham) with energy of 0.662 MeV. The source activity during the experiment was 8mCi. Six shielding materials are used in the present study : lead, brass, copper, steel, iron, and concrete (different types).

The first five materials have cylindrical forms with different thicknesses. The concrete block was made with dimensions of 10 cm × 10cm × 3cm .

Ordinary concrete was made of cement, sand and stones, whereas other types were prepared by adding fractional weights of iron or brass or lead to the ordinary concrete as shown in Table 1.

**Table 1.** The fractional weights of concrete types.

| Types of concretes | Fractional weights of component materials (%) | | | | | | Density (gm/cm$^3$) |
|---|---|---|---|---|---|---|---|
| | Cement | Sand | Stone | Iron | Brass | Lead | |
| Concrete 1 | 14.3 | 28.6 | 57.1 | | | | 2.38 |
| Concrete 2 | 14.3 | 28.6 | 49.8 | 14.3 | | | 2.35 |
| Concrete 3 | 12.5 | 25 | 50 | 12.5 | | | 2.39 |
| Concrete 4 | 12.5 | 25 | 50 | | 12.5 | | 2.44 |
| Concrete 5 | 12.5 | 25 | 50 | | | 12.5 | 2.46 |
| Concrete 6 | 11.2 | 22.2 | 44.4 | | | 22.2 | 2.7 |
| Concrete 7 | 9.1 | 18.2 | 36.35 | | | 36.35 | 3.05 |

The electronic system for measurement was arranged, using a suitable operating voltage and gain as shown in Figure 1. The distance between the source and the detector was adjusted to be 60cm and the accumulation time for gamma-ray spectra was 3600 sec. Measurements were carried out for each shielding material, and gamma-ray absorption coefficients were calculated.

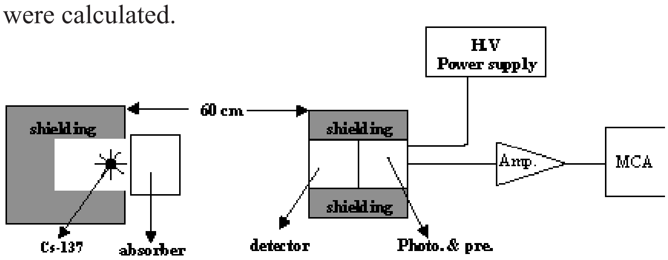


**Figure 1.** Measurement system setup.

Gamma-ray absorption coefficients were measured and calculated for the materials used in the present study as a single layer absorber using Cs-137. The results are tabulated in Table 2.

A comparison of the present data with those published data (which are theoretical) of for iron, steel, copper, lead and concrete, show that the present data is deviated from the published by percentage of 0.37, -0.7, -0.2, 2.2, -0.8,-4.0, respectively.

The deviation may be due to the statistical errors associated with the measurements.

**Table 2.** Gamma-ray absorption coefficients in the studied materials.

| Material | Linear absorption coefficient (cm$^{-1}$) | | Mass absorption coefficient (cm$^2$ / gm) | |
|---|---|---|---|---|
| | Measured | Published [19] | Measured | Published [19] |
| Iron | 0.547 | 0.545 | 0.0699 | 0.0690 |
| Steal | 0.566 | 0.570 | 0.0719 | 0.0724 |
| Copper | 0.636 | 0.650 | 0.0712 | 0.0725 |
| Brass | 0.600 | 0.605 | 0.709 | 0.0715 |
| Lead | 1.172 | 1.260 | 0.1033 | 0.1057 |
| Concrete 1 | 0.163 | 0.170 | 0.0702 | 0.0723 |
| Concrete 2 | 0.170 | | 0.0723 | |
| Concrete 3 | 0.168 | | 0.0703 | |
| Concrete 4 | 0.179 | | 0.0734 | |
| Concrete 5 | 0.186 | | 0.0756 | |
| Concrete 6 | 0.213 | | 0.0789 | |
| Concrete 7 | 0.247 | | 0.0810 | |

Particle size of the additive materials is:

For Iron = 3x10$^{-3}$ – 4 mm$^3$ , For Brass = 1.02x10$^{-3}$ – 4 mm$^3$ ,

For Pb = 1.03x10$^{-4}$ – 4 mm$^3$.

Brass composition (%)= 72.4 Cu+27.6 Zn.

Steel composition(%) = Fe=36.46, Cu=35.00, Cr=18.30, Ni=8.11, C=0.06, Si=0.0242, Mn=1.408, P=0.03, S=0.023, MO=0.28, V=0.075, W=0.024, Ti=0.002, Sn=0.038, CO=0.14, Al=0.007 , Nb=0.019.

The results are discussed with the view point that the probability of interaction of gamma-ray with matter is proportional to the material atomic number ( or density), and is inversely proportional with the photon energy except for pair production.

The difference between copper (Z=29) and iron (Z=26) atomic number is 3 while it is 56 between lead (Z=82) and iron , therefore the difference between their absorption coefficients is small for the first case , whereas it is large for the second case.

The ordinary concrete has a low average atomic number compared to that containing additive materials of a relatively high atomic number , therefore the absorption coefficient of ordinary concrete is lower than those of the other types containing additive materials.

The material with a high density has a high absorption coefficient compared with those of low densities . Iron and steel have the same atomic number(Z=26), but they have heavily different densities ( $_{iron}$=7.83 gm/cm$^3$, $_{steel}$=7.87 gm/cm$^3$), therefore steel has a relatively higher absorption coefficient than that of iron, for the same gamma-ray energy. Copper (Z=29) and brass ($Z_{eff.}$=29.28) have approximately the same atomic number, but they have different densities ( $_{cu}$=8.96 gm/cm$^3$, $_{brass}$=8.46gm/cm$^3$) . The absorption coefficient of copper is higher than that of brass; this is due to a high density of copper.

The absorption coefficients of 0.662 MeV gamma-ray in concrete 1 , concrete 2, and concrete 3 are slightly different, this is due to the relatively low atomic number and density of the additive material (iron). The difference in absorption coefficients is clear in case of concrete 4 , where the additive material is brass , which has a higher average atomic number and density than iron.

The difference is considerable in concrete 5, concrete 6 and concrete 7, where additive material is the lead , which has a higher atomic number and density than brass and iron. For this reason, an increase of 12.5%, 22.2% and 36.4% fractional weights of lead added to ordinary concrete, correspond to 11.5% , 27.9% and 48.9% increment of absorption coefficient , respectively .

As a conclusion, addition of fractional weights of lead to ordinary concrete increases the value of absorption coefficients, hence reduces shielding thickness and cost.

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